GB 2292405A

(12) UK Patent Application (19) GB (11) 2 292 405 (13) A

(43) Date of A Publication 21.02.1996

(21) Application No 9416813.5

(22) Date of Filing 19.08.1994

(71) Applicant(s)
McDermott International Inc

(Incorporated in Panama)

P.O.Box 60035, 1450 Poydras Street, New Orleans, Louisiana 70160, United States of America

(72) Inventor(s)
John Simmons

(74) Agent and/or Address for Service
D Young & Co
21 New Fetter Lane, LONDON, EC4A 1DA, United Kingdom

(51) INT CL[6]
E02B 17/00

(52) UK CL (Edition O)
E1H HB H602 H606

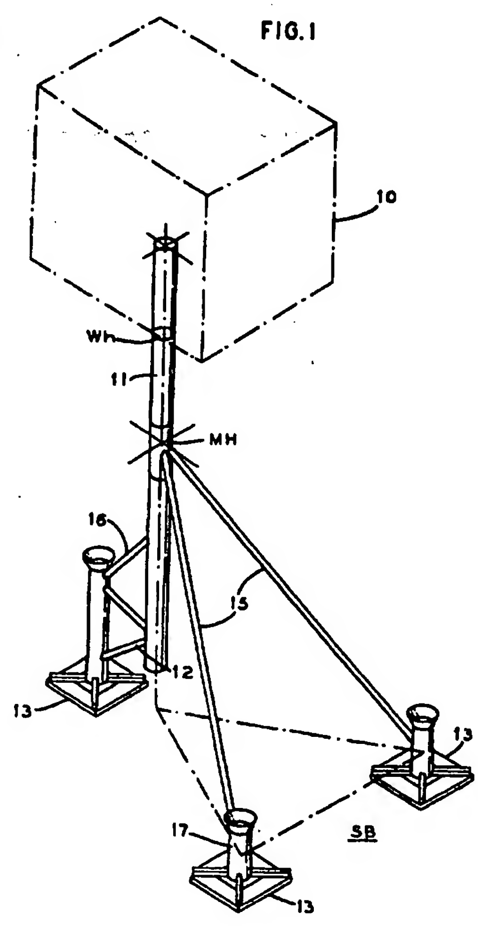
(56) Documents Cited
GB 2267525 A GB 2136860 A GB 2136482 A
GB 1037558 A EP 0122719 A1 WO 90/08232 A1

(58) Field of Search
UK CL (Edition M) E1H HB HCA HCD
INT CL[5] E02B 17/00 17/02, E02D 29/06

(54) Offshore structures.

(57) An offshore structure and method of repositioning the structure comprises a vertically extending service caisson 11 which contains service items needed between a fixture 10 on the offshore structure and the sea bed SB. Bracing elements 15 are connected between mid-height or lower, on the caisson 11, and a plurality of foundations 13 fixed to the sea bed SB. The effective frontal profile of the structure increases from near the top of the structure to the sea bed SB. In this way, the effective frontal profile for an offshore structure can be such that the environmental forces acting upon it do not vary and are approximately constant despite variations in water depth. In this way, the same structure can be used at a variety of depths without having to reconfigure the structure to accommodate environmental and wave forces at the new site. The structure may be removed from a first site, the length of the caisson adjusted if necessary, the foundations replaced if necessary and the structure then attached to the sea bed at a second site.

FIG. 1



GB 2 292 405 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

FIG.1

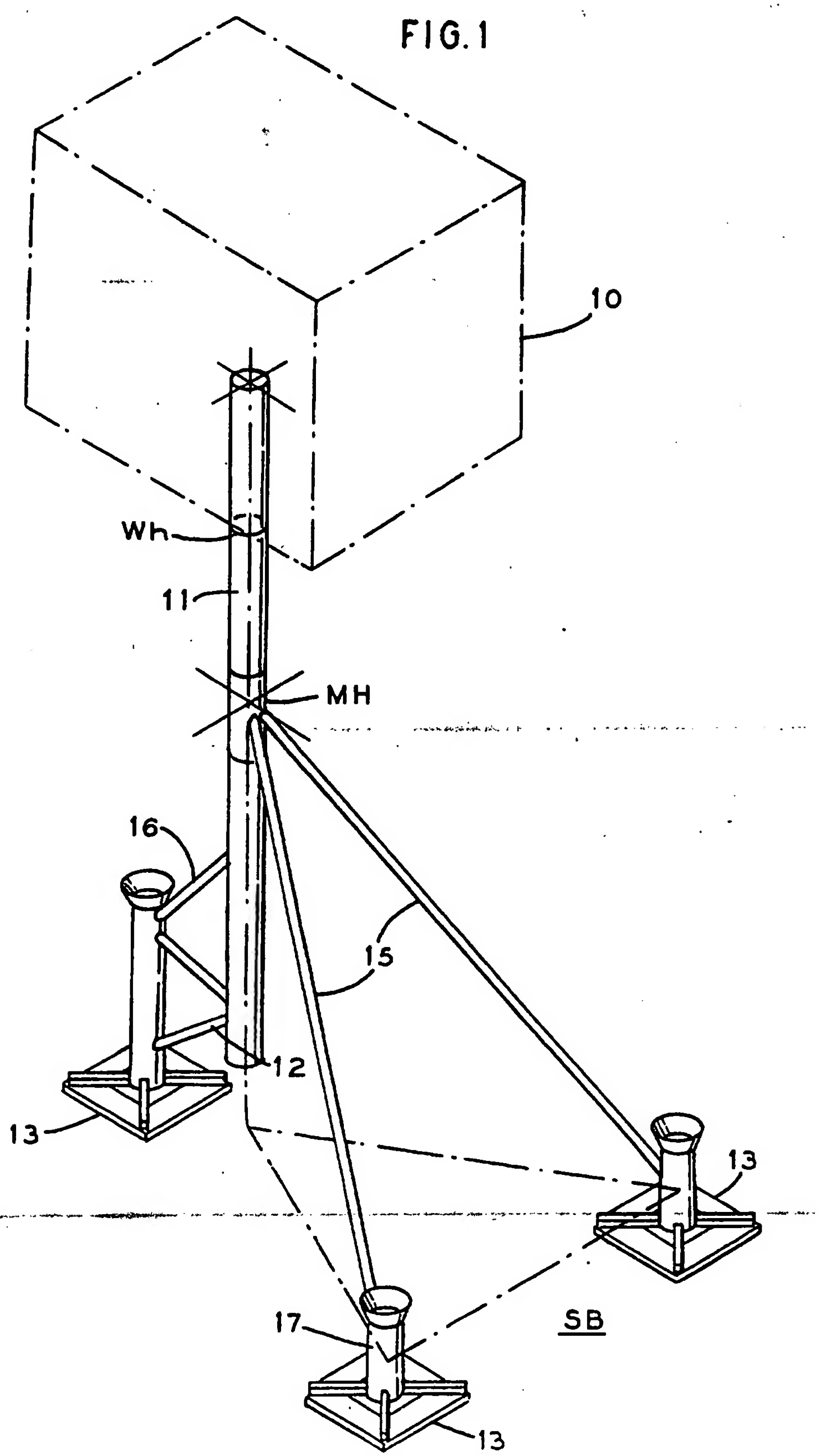


FIG.2

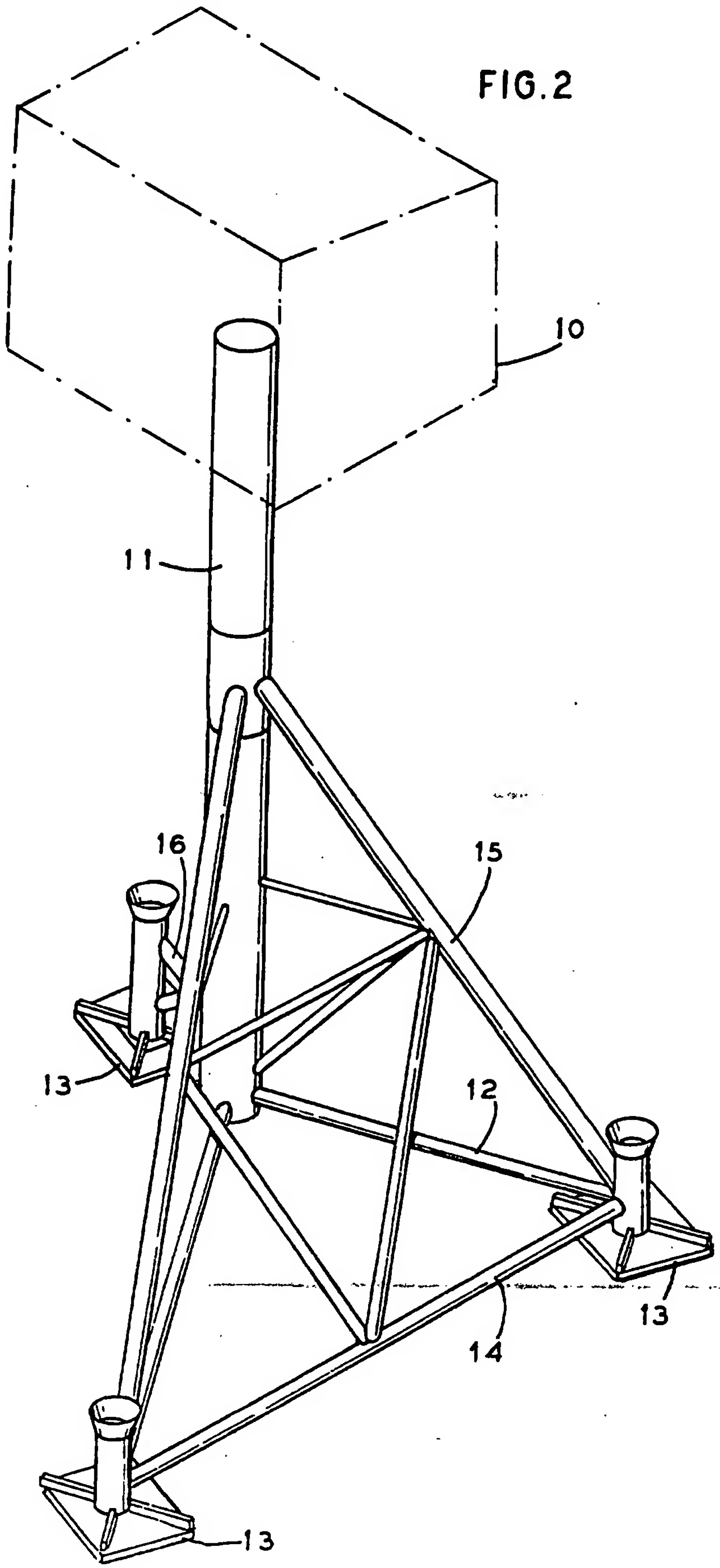


FIG. 3

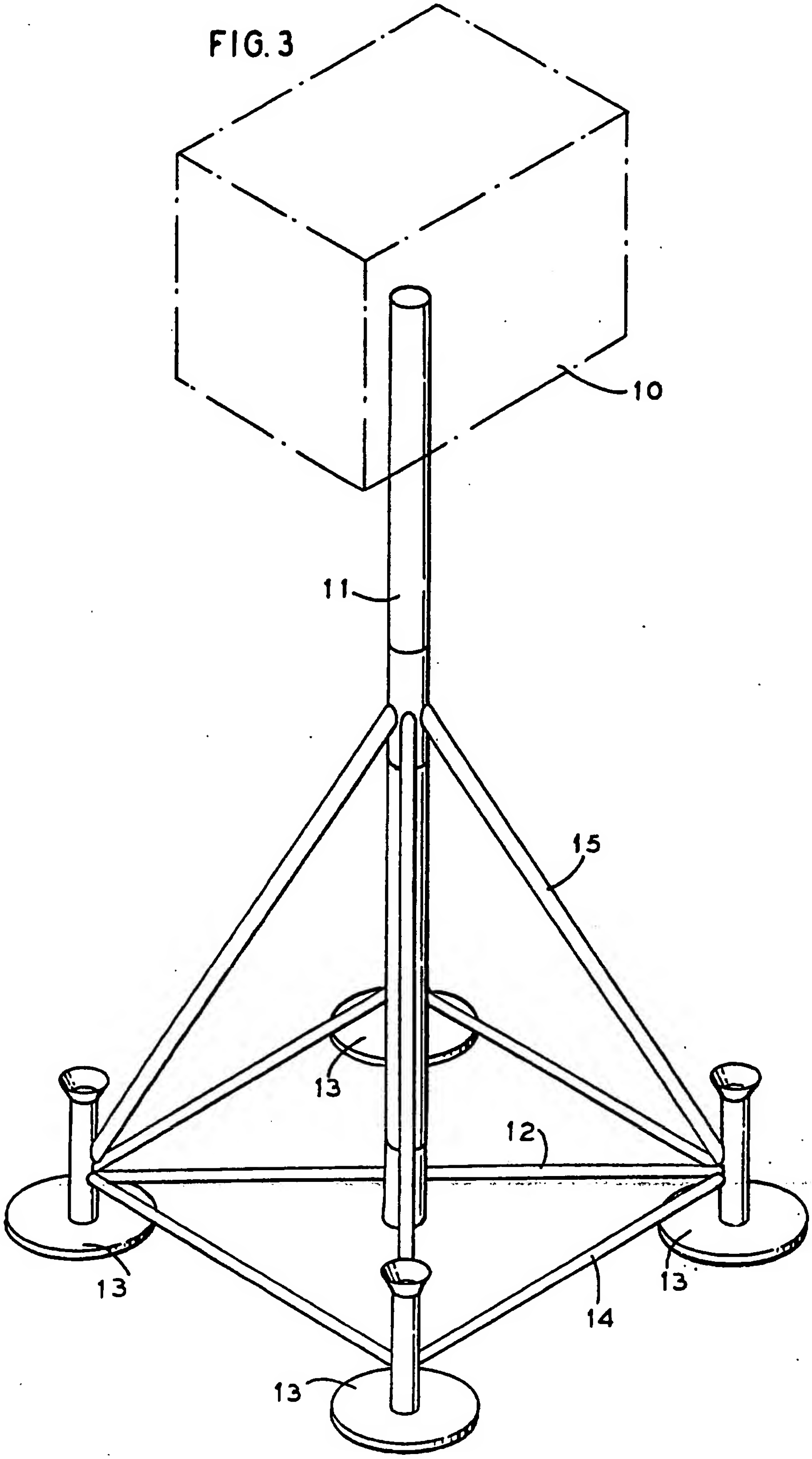


FIG.4

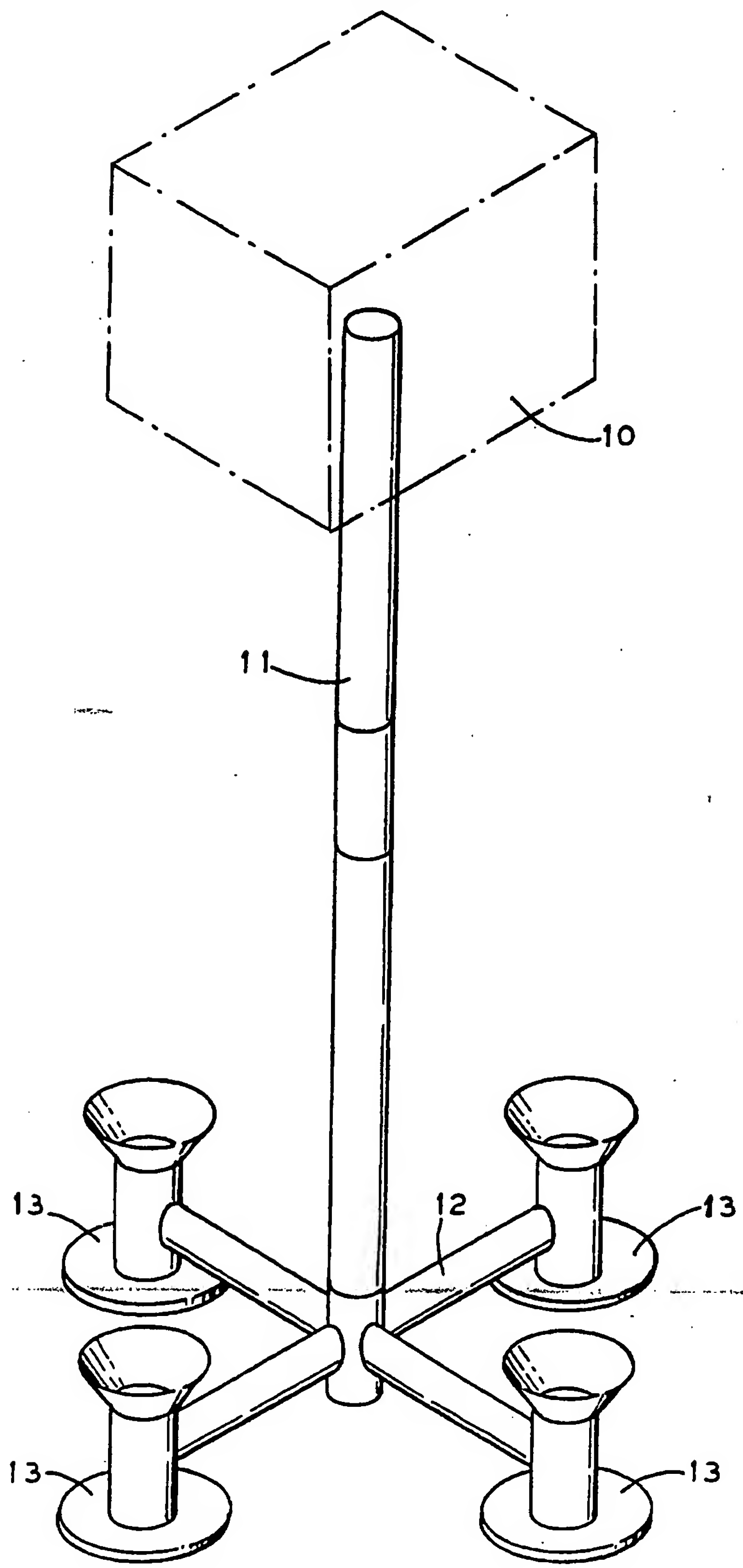


FIG. 5

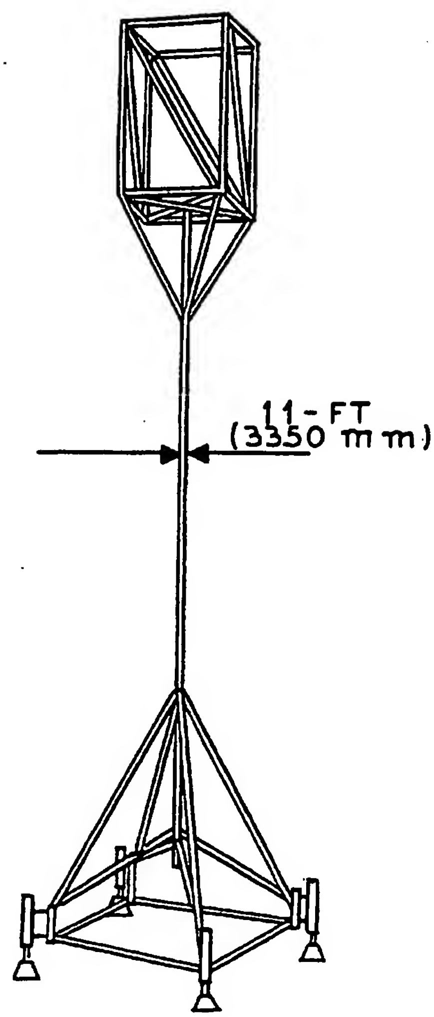


FIG.6

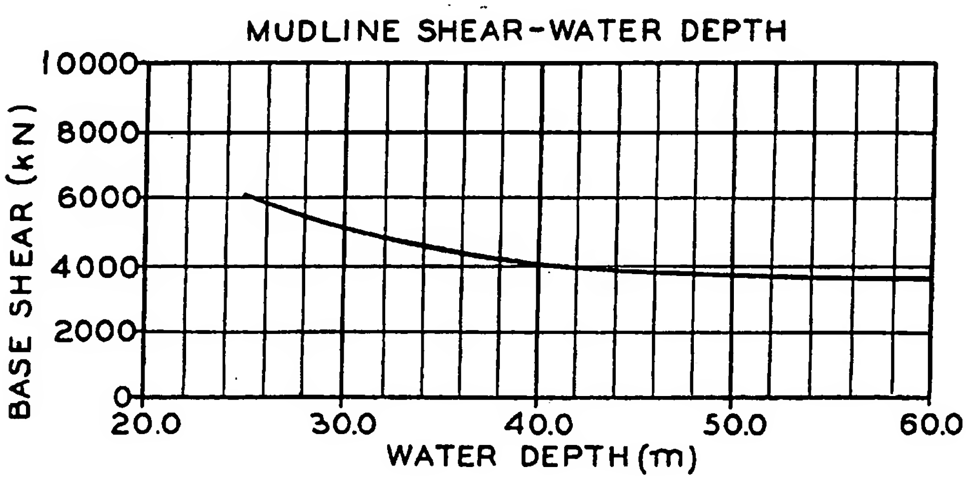
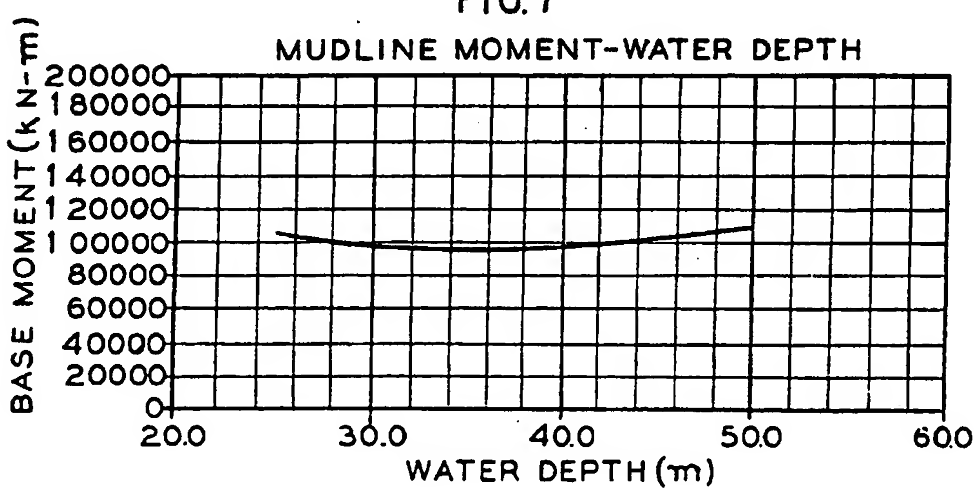

MUDLINE SHEAR-WATER DEPTH
BASE SHEAR (kN)
10000
8000
6000
4000
2000
0
20.0
30.0
40.0
50.0
60.0
WATER DEPTH (m)

FIG. 7


MUDLINE MOMENT-WATER DEPTH
BASE MOMENT (kN-m)
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
20.0
30.0
40.0
50.0
60.0
WATER DEPTH (m)

2292405

OFFSHORE STRUCTURES

The invention relates to offshore structures.

Offshore structures designed to support modules, decks or buildings used for production or drilling of oil, gas or other minerals, generally include a tower structure for supporting the module, deck or building, above the water level, in particular above the anticipated highest wave crest of the water level. The tower structure is generally in the form of a central column or caisson, which contains services such as conductors, risers and the like for establishing communications and functions between the module, platform, deck or building at the top of the tower, collectively, the fixture, and the area adjacent the sea bed, at the bottom of the tower. The tower structure is also known to include a framework for supporting the central column, and a plurality of foundations attached to the sea bed and connected to the framework.

The structures are each capable of use at a particular location where the environmental conditions are known. The structures are specifically designed to suit those conditions. If a different offshore site at a different depth and/or exposed to different environmental conditions is needed, a new tower structure must be designed and constructed.

Examples of known offshore tower structures are disclosed in U.K. Patent Application GB-A-2 116 237, U.K. Patent Application GB-A-2 136 860 and U.K. Patent Application GB-A-2 267 525. All three of these references disclose offshore structures including tower structures having a central column for supporting a fixture or platform above the water level, a framework for supporting the central column and a foundation of various designs which are suited for anchoring the framework to the sea bed at a particular site. It is known that an offshore structure must be designed to withstand the wave forces that are anticipated at a particular site. None of the references teach how a single tower structure used at one site having one set of environmental conditions and/or depth, can be used at a different site that may be under different environmental conditions and/or depths.

According to one aspect of the present invention there is provided an offshore structure for supporting a fixture above a wave

crest and over the sea bed, the sea bed being at any depth within a selected range of depths, comprising: a vertically extending central service caisson having an upper end for supporting the fixture and a lower end for positioning adjacent the sea bed; a plurality of bracing elements connected to the caisson no higher than a mid-height of the caisson; the caisson and bracing elements having a combined effective frontal profile which increases either continuously or discontinuously from the upper end of the caisson to the lower end of the caisson, with shape, dimensions and configuration for the caisson with the bracing elements being selected to produce environmental forces from wave action on the effective frontal profile which is approximately constant for any water depth within the selected range of water depths; and a plurality of foundations for attachment to the sea bed, connected to the caisson through the bracing elements.

According to another aspect of the present invention there is provided a method of utilizing a single offshore structure for reuse at multiple water depths within a selected range of water depths, the offshore structure carrying a fixture above a water crest level, and attaching the fixture to the sea bed, comprising the steps of: designing the offshore structure to have a vertically extending central service caisson having an upper end for supporting the fixture and a lower end for positioning adjacent the sea bed; the structure having a plurality of bracing elements connected to the caisson no higher than a mid-height of the caisson, the caisson and bracing elements having a combined effective frontal profile which increases either continuously or discontinuously, from the upper end of the caisson to the lower end of the caisson, with shape, dimensions and configuration for the caisson with the bracing elements being selected to produce environmental forces from wave action on the effective frontal profile which is approximately constant for any water depth within the selected range of water depth, and a plurality of foundations for attachment to the sea bed, connected to the caisson through the bracing elements; attaching the offshore structure at a first location having a first water depth using foundations suited to the sea bed at the first location; removing the offshore structure from the first location in preparation for attaching the offshore structure to a second location at a second water depth; adjusting the length of the caisson so that

the fixture will be above the water crest level at the second location; if needed, replacing the foundations so that they are suited for anchoring to the sea bed at the second location; and attaching the offshore structure at the second location using the foundations suited to the sea bed at the second location.

Preferred embodiments of the present invention provide improved structures and techniques for use of the structure at different locations where the water depth differs, and to a certain extent where environmental conditions may also differ, but primarily where the wave climate may not be significantly different. This is achieved by designing the supporting column and bracing for the column with shapes and dimensions proportioned so that the environmental effects from wave actions induce total forces that are approximately constant, despite variations in water depth, within a certain range of water depth; typically between about 20 and 50 metres. The actual water depth at the site need not be known in advance, as long as it is within this range. The structure can be moved from one site then reinstalled at another site. The column may have to be extended or reduced, to ensure that the module or deck is clear of the wave crest and has a sufficient air gap thereover. The foundations to which the structure is connected are also specific to the sea bed conditions at the new site, which may be different from the conditions at the previous site. They may have to be replaced.

The preferred embodiments permit the reuse of the same structure at another location where the water depth can be significantly different (but within the selected range) and the environmental forces acting on the structure will not affect the capacity of the elements to resist those forces. This precludes the need to strengthen the elements, which would involve considerable additional time and expense, to the extent that reuse of the same structure would become uneconomical. It is also necessary, by law, to remove all offshore structures in shallow water in the North Sea, at the operator's expense. The preferred embodiments of the present invention provide the operator with an actual advantage to remove the structure, since now it can be reused at another site. This is particularly important where marginally economically oil field development is involved.

The structure can also be pre-built and stored until it is

required. It is then available on short notice. The fact that a single structure can be designed for multiple sea depths makes this possible. There is no cost involved in redesigning the structure to be waveload independent and the size of the elements are economical and efficient. The structure can be built at a time which is advantageous to the operator, for example, when fabrication costs are low, rather than at peak periods when prices are high.

Although the structure would have to be recertified for each location where it is to be used, because the foundations will almost certainly have to be different, careful design according to the criteria embodying the present invention will facilitate recertification without difficulty. To modify the structure for a new water depth and sea bed properties are relatively simple operations and the design calculations and analysis can be reproduced fairly quickly and simply. This also saves design time and costs.

A basis for the present invention is the realization that the wave forces and moments exerted on the structure are greater near the water surface and least near the sea bed. Keeping this in mind, the dimensions and spacial configurations of the elements of the preferred embodiments are selected to be greatest below the middle of the central service caisson, and generally to have an effective frontal profile which increases continuously or discontinuously, from an upper end of the structure, to a lower end thereof.

Specific examples of the offshore structure with constant waveload profile according to embodiments of the present invention, and a method of utilizing the structure at different depths, will now be described with reference to the accompanying drawings in which:

Figure 1 is a perspective view of an offshore structure with support bracing at or about mid-height of the central service caisson and support bracing at or near the bottom end of the central service caisson;

Figure 2 is a perspective view of an offshore structure with support bracing at or about mid-height of the central service caisson and with secondary bracing to provide stability to that bracing, and bracing at or near the bottom end of the central service caisson;

Figure 3 is a perspective view of an offshore structure with support bracing at or about mid-height of the central service caisson

and support bracing at or near the bottom end of the central service caisson, and bracing connecting the foundations, with the bracing and foundations being arranged around the central service caisson;

Figure 4 is a perspective view of an offshore structure with bracing at or near to the bottom of the central service caisson;

Figure 5 is a schematic representation of a generic configuration used in an example of the present invention;

Figure 6 is a graph plotting water depth against base shear for the configuration of Figure 5; and

Figure 7 is a graph similar to Figure 6 but plotting water depth against base moment.

Throughout the figures, the same reference numerals are utilized to designate the same or functionally similar parts.

As can be seen from the figures, the invention can take several forms. There are certain similarities between each configuration and these similarities are associated with the degree of bracing provided and the requirement that the offshore structure exhibits a similar environmental profile, irrespective of the depth of water at the site where the offshore structure is to be located and attached.

The effects of waves on an offshore structure will produce pressures on the elements of the offshore structure. The pressure is dependent on the water particle velocity and acceleration, and decays exponentially with depth. The higher pressures are near the surface and very much lower pressures are near the sea bed. The effect of pressure on an offshore structure is to produce a force and overturning moment due to the effective frontal profile presented to the water particles. By selecting a configuration and dimensions of the elements of the offshore structure, it is possible to arrange for the higher pressures near the water level to act on a part of the offshore structure with a smaller frontal profile closer to the top of the structure. It is also possible to ensure that, with changes in water depth, the pressure acting on the frontal profile, a combined action that is similar for a selected range of water depths, e.g. about 20 to 50 metres, will be produced. It is possible to form an offshore structure that is economical to fabricate and install and has the advantage that it is independent of water depth with respect to the wave forces induced.

Referring to Figure 1, there is shown a module, platform, deck or building 10, which we will term a fixture, and which is supported by a central service caisson 11. The central service caisson 11 is a tube of relatively thin wall material and of constant or varying diameter. The central service caisson 11 contains piping, drilling caissons and conductors, umbilicals or any other services required for the facilities contained in the fixture 10, or to enable the production or drilling of oil, gas or other minerals or for any other activity for which the offshore structure is to be used. Caisson 11 must be long enough to support fixture 10 above a wave crest on water level WL.

The wave loading on the items inside the central service caisson 11 is minimized by locating them inside the tube. The central service caisson 11 is supported by one or more bracing elements 15, connected to the central service caisson 11, at or about mid-height MH and to a plurality of foundations 13. The central service caisson 11 is supported by one or more bracing elements 12 and 16, located at or about the bottom end of the central service caisson 11. The bracing elements 12 and 16 can be arranged to form one or more trusses. The bracing elements 12 and 16 are connected to the foundations 13. The foundations 13 can be piles, spread footings or of the suction pad type, or a combination of these types, for attaching the structure to the sea bed SB.

Referring to Figure 2, the central service caisson 11 is supported by one or more bracing elements 15 connected to the central service caisson at or about mid-height and to the foundations 13. The central service caisson is supported by one or more bracing elements 16 located at or about the bottom end of the central service caisson. The bracing elements 15 and 16 can be arranged to form one or more trusses. The bracing elements 15 and 16 are braced by elements connecting them together or to the central service caisson, or to braces 14 connecting the foundations 13. The bracing elements 15 and 16 are connected to the foundations 13. The foundations 13 can be piles, spread footings or of the suction pad type, or a combination of these types.

Referring to Figure 3, the central service caisson 11 is supported by one or more bracing elements 15 connected to the central service caisson 11 at or about mid-height and to the foundations 13. The central service caisson 11 is supported by one or more bracing

elements 12 located at or about the bottom end of the central service caisson 11. The bracing elements 12 can be horizontal or pitched at an angle and the end of the central service caisson 11 can be at a considerable distance from the sea bed. The bracing elements 14 connect the foundations 13. The bracing elements 12 and 15 are connected to the foundations 13. The foundations 13 can be piles, spread footings or of the suction pad type, or a combination of these types.

Referring to Figure 4, the central service caisson 11 is supported by one or more bracing elements 12 connected to the central service caisson 11 at or about the bottom end and to the foundations 13. The bracing elements 12 can be horizontal, angled, or pitched at an angle and the end of the central service caisson 11 can be at a considerable distance from the sea bed. The bracing elements 12 are of a constant or varying cross-section. The foundations 13 can be piles, spread footings or of the suction pad type, or a combination of these types.

Returning to Figure 1, the asymmetric structure was selected for supporting the mid-height of the caisson 11 using the angled bracing elements 15, from one side of the fixture and caisson, and the angled bracing elements 12 and 16 which are connected preferentially to the lower end of the caisson, and on an opposite side of the fixture and caisson. Foundations 13 are three in number and include hollow central tubes 17 with funnel-shaped upper ends, of the type for receiving a pile (not shown) which can be anchored through the pipe 17 to fix the foundation to the sea bed SB.

In the embodiment of Figure 2, the asymmetric lower bracing element 16 is used in conjunction with the angled bracing elements 15 and the further cross bracing elements 12 and 14.

Figure 3 is a symmetrical structure of four foundations 13 connected to each other by bracing elements 14, and connected to the lower end of the caisson 11 with bracing elements 12. The angled bracing elements 15 further connect the mid-height of the caisson 11 to the foundations 13.

Figure 4 uses heavy bracing elements 12 to connect the foundations 13 to the lower end of the caisson 11 with no direct bracing elements connected between the foundations and the mid portion

of the caisson. If needed, stability of the fixture above wave crest can be increased by using cables (not shown) connected between an upper end of the caisson 11, and the sea bed. These have very small effective frontal profiles so they do not greatly affect the constant configuration of the offshore structure.

In each of the embodiments, the total surface area of the structure facing the oncoming waves or wave force, that is, the effective frontal profile (EFP) of the structure, increases either continuously or discontinuously, as the sea depth along the caisson 11 varies.

To proportion a structure to have a constant wave load profile for a particular range of water depths, the method described herein will enable the size of the profile width to be determined at the various elevations.

For the determination of the wave properties, it is assumed that Stokes Fifth Order Gravity Wave Theory can be applied. For the calculation of the wave forces, Morison's Equation has been assumed to be appropriate.

A single vertical monopile like that shown in Figure 5 is used to represent the structure. The variation of the hydrodynamic pressures along the length can be obtained for a certain water depth, wave height and period. By defining the profile width, the unit loading can be obtained, and the total forces acting, by integrating over the length from sea bed to surface.

If this is repeated for another water depth or for several water depths, it is possible to obtain the profile width that will give an approximately constant wave load for the range of water depths selected. It may be necessary to choose the best solution in a least square sense to give a profile width for a particular elevation along the length of the monopile.

The calculation method is as follows:

1. For a reference water depth, usually taken as the upper water depth, and wave height and wave period, calculate the pressures along the length of the monopile, using a particular wave theory, usually Stokes Fifth Order, and Morison's Equation.
2. Integrate the pressure along the length of the monopile from sea bed to surface.

$$P = \int p^* \, dy$$

where:

P = total pressure

p = pressure at elevation Y

$y = Y/D_{ref}$

Y = distance from sea bed to a particular elevation

D_{ref} = the instantaneous water depth from sea bed to surface

3. Determine the theoretical profile width for the reference water depth for various elevations along the length of the monopile.

$$d_{ref} = \sqrt{\{p^* k/P\}}$$

where:

d_{ref} = profile width at elevation Y

P = total pressure

p = pressure at elevation Y

k = width dimension to give d_{ref} correct size proportion

4. Repeat the procedure for another water depth except evaluate the theoretical profile width as follows:

$$d_y = (Dref/D)^2 * \sqrt{\{P^* k/P\}}$$

where:

D_{ref} = the reference instantaneous water depth

D = instantaneous water depth

P = pressure at elevation Y

k = width dimension to give D_{ref} correct size proportion

5. There will be a theoretical profile width for each water depth and for each location along the monopile length. The theoretical profile width will vary by a small amount for each case. By fitting a curve of the profile width versus the elevation for water depth, it is possible to average the values at a particular elevation. Where the water depth is less than the reference water depth, the profile width at the surface is taken for elevation above the surface. A curve can then be fitted to the average theoretical profile widths versus elevation. The values calculated by this curve are the actual profile widths to be used. The curve used can be of the form indicated below:

$$d_y = A_0 + \sqrt{\{Y\}} + A_2 * Y$$

where:

d_y = actual profile width at elevation Y

A_0, A_1, A_2 = coefficients

In the following are examples of the evaluation of the actual profile widths calculated by the method described.

Example 1 is for a monopile with the wave height and period constant for the range of water depths.

Upper water depth	50 m
Lower water depth	25 m
Wave Height	16 m
Wave Period	12.5 sec
Water Density	10.5 k/N/cu m
Current Velocity at surface	2.5 m/sec
Marine Growth Allowance	0.05 m

EXAMPLE 1

water depth = 50 **water elevation = 59.478**

y/d	pressure	theoretical profile width	theoretical horiz shear	actual profile width	actual horiz shear	constant profile width	constant horiz shear
0	1.47	0.950		1.256		4.000	
0.1	5.41	1.823	33.49	1.881	35.75	4.000	81.86
0.2	6.22	1.955	65.48	2.205	71.04	4.000	138.34
0.3	7.06	2.083	79.87	2.481	92.86	4.000	157.96
0.4	8.08	2.228	97.27	2.730	117.70	4.000	180.12
0.5	9.39	2.402	120.60	2.964	148.35	4.000	207.81
0.6	11.09	2.611	153.15	3.186	187.81	4.000	243.62
0.7	13.35	2.864	199.76	3.399	239.95	4.000	290.72
0.8	16.36	3.171	287.95	3.605	310.29	4.000	353.43
0.9	20.45	3.544	369.80	3.805	406.74	4.000	437.89
1	26.04	4.000	525.21	4.000	541.09	4.000	552.98
2.614	661.39	406.41	1912.59	0.5343	2151.59		2644.74

water depth = 45 **water elevation = 54.676**

y/d	pressure	theoretical profile width	theoretical horiz shear	actual profile width	actual horiz shear	constant profile width	constant horiz shear
0	1.87	1.256		1.256		4.000	
0.1	6.17	2.283	44.94	1.850	37.64	4.000	87.90
0.2	7.04	2.439	85.49	2.157	72.76	4.000	144.52
0.3	7.95	2.592	103.31	2.417	94.09	4.000	164.00
0.4	9.06	2.766	124.87	2.652	118.23	4.000	186.06
0.5	10.47	2.974	153.67	2.871	147.89	4.000	213.62
0.6	12.31	3.225	193.71	3.079	185.86	4.000	249.20
0.7	14.74	3.529	250.76	3.279	235.81	4.000	295.88
0.8	17.98	3.897	333.75	3.472	302.82	4.000	357.85
0.9	22.35	4.346	466.96	3.660	394.25	4.000	441.02
1	28.30	4.890	643.75	3.843	520.94	4.000	553.93
	673.80		2391.22		2110.29		2694.01

EXAMPLE 1 [continued]

water depth = 40 water elevation = 49.943

y/d	pressure	theoretical profile width	theoretical horiz shear	actual profile width	actual horiz shear	constant profile width	constant horiz shear
0	2.39	1.677		1.256		4.000	
0.1	7.12	2.895	61.51	1.820	39.87	4.000	95.06
0.2	8.07	3.082	113.64	2.109	74.89	4.000	151.88
0.3	9.08	3.267	136.19	2.352	95.83	4.000	171.32
0.4	10.30	3.480	163.53	2.573	118.46	4.000	193.52
0.5	11.86	3.735	200.11	2.778	148.42	4.000	221.34
0.6	13.90	4.043	250.94	2.972	185.43	4.000	257.31
0.7	16.59	4.417	323.27	3.159	234.00	4.000	304.52
0.8	20.17	4.871	428.32	3.339	299.04	4.000	367.20
0.9	25.01	5.423	584.02	3.514	387.63	4.000	451.30
1	31.60	6.096	819.65	3.685	510.15	4.000	565.43
	694.99		3081.17		2094.73		2778.84

water depth = 35 water elevation = 45.307

y/d	pressure	theoretical profile width	theoretical horiz shear	actual profile width	actual horiz shear	constant profile width	constant horiz shear
0	3.10	2.262		1.256		4.000	
0.1	8.35	3.714	86.11	1.789	42.63	4.000	103.72
0.2	9.40	3.942	154.23	2.060	77.71	4.000	160.88
0.3	10.53	4.172	183.51	2.287	98.45	4.000	180.66
0.4	11.92	4.438	219.37	2.493	121.89	4.000	203.46
0.5	13.71	4.759	267.62	2.684	150.66	4.000	232.23
0.6	16.05	5.150	334.98	2.865	187.50	4.000	269.64
0.7	19.15	5.625	431.22	3.039	235.97	4.000	318.95
0.8	23.30	6.205	571.53	3.206	301.02	4.000	384.68
0.9	28.92	6.913	780.36	3.368	389.86	4.000	473.20
1	36.60	7.777	1097.70	3.526	513.04	4.000	593.75
	730.41		4126.63		2118.73		2921.17

EXAMPLE 1 (continued)

water depth = 30 **water elevation = 40.804**

y/d	pressure	theoretical profile width	theoretical horiz shear	actual profile width	actual horiz shear	constant profile width	constant horiz shear
0	4.09	3.081		1.256		4.000	
0.1	9.99	4.818	123.90	1.757	46.30	4.000	114.91
0.2	11.20	5.100	214.73	2.010	81.76	4.000	172.96
0.3	12.51	5.391	254.14	2.222	102.67	4.000	193.53
0.4	14.16	5.735	303.30	2.413	126.46	4.000	217.70
0.5	16.30	6.153	370.35	2.501	155.89	4.000	248.64
0.6	19.14	6.667	464.99	2.758	193.87	4.000	289.27
0.7	22.93	7.297	601.65	2.919	244.23	4.000	343.33
0.8	28.04	8.070	803.07	3.073	312.37	4.000	416.01
0.9	36.02	9.019	1106.19	3.223	406.17	4.000	514.74
1	44.65	10.183	1571.99	3.369	537.23	4.000	650.25
	700.05		5814.30		2206.94		3161.33

water depth = 25 **water elevation = 36.484**

y/d	pressure	theoretical profile width	theoretical horiz shear	actual profile width	actual horiz shear	constant profile width	constant horiz shear
0	5.59	4.238		1.256		4.000	
0.1	12.39	6.307	185.80	1.725	51.83	4.000	131.24
0.2	13.82	6.661	310.45	1.961	88.46	4.000	191.26
0.3	15.43	7.039	366.07	2.158	110.20	4.000	213.47
0.4	17.50	7.496	437.50	2.334	135.29	4.000	240.35
0.5	20.24	8.061	536.99	2.498	166.78	4.000	275.45
0.6	23.92	8.763	680.11	2.653	208.01	4.000	322.30
0.7	28.92	9.635	890.70	2.800	263.50	4.000	385.61
0.8	35.77	10.716	1207.50	2.943	339.75	4.000	472.07
0.9	45.28	12.058	1695.01	3.081	446.46	4.000	591.45
1	58.62	13.718	2462.80	3.215	598.20	4.000	758.22
	894.21		8772.93		2408.47		3581.42

EXAMPLE 1 [continued]

water depth	summary of theoretical total shear	summary of actual total shear	summary of constant total shear
50	1912.59	2151.59	2644.74
45	2391.22	2110.29	2694.01
40	3081.17	2094.73	2778.84
35	4126.63	2118.73	2921.17
30	5814.30	2206.94	3161.33
25	8772.93	2408.47	3581.42

The summary of the actual mud line shear forces gives 2200 kN approximately for the range of water depths.

Example 2 is similar to the example above except that the wave height and period has been taken to be that expected for the particular water depth over the range.

Water Depth	Wave Height (Hw)	Wave Period
50 m	16.00 m	12.5 sec
45 m	15.75 m	12.5 sec
40 m	15.50 m	12.5 sec
35 m	15.00 m	12.5 sec
30 m	14.50 m	12.5 sec
25 m	14.00 m	12.5 sec

EXAMPLE 2

water depth = 50 **water elevation = 59.478**

y/d	pressure	theoretical profile width	theoretical horiz shear	actual profile width	actual horiz shear	constant profile width	constant horiz shear
0	1.47	0.950		1.280		4.000	
0.1	5.41	1.823	33.49	1.989	37.60	4.000	81.84
0.2	6.22	1.965	65.48	2.324	74.97	4.000	138.31
0.3	7.06	2.083	79.87	2.597	97.48	4.000	157.92
0.4	8.08	2.228	97.27	2.828	122.71	4.000	180.08
0.5	9.39	2.402	120.60	3.058	153.57	4.000	207.77
0.6	11.09	2.611	153.15	3.265	193.08	4.000	243.57
0.7	13.35	2.854	199.76	3.460	245.00	4.000	290.66
0.8	16.36	3.171	267.95	3.647	314.76	4.000	353.36
0.9	20.45	3.544	369.80	3.826	410.07	4.000	437.80
1	26.04	4.000	525.21	4.000	542.31	4.000	552.86
2.614	661.39	406.41	1912.59	0.5136	2191.52		2644.17

water depth = 45 **water elevation = 54.498**

y/d	pressure	theoretical profile width	theoretical horiz shear	actual profile width	actual horiz shear	constant profile width	constant horiz shear
0	1.81	1.262		1.280		4.000	
0.1	6.06	2.308	44.37	1.956	38.64	4.000	85.83
0.2	6.92	2.466	84.85	2.273	75.19	4.000	141.52
0.3	7.81	2.620	102.29	2.532	96.77	4.000	160.57
0.4	8.89	2.795	123.51	2.760	120.76	4.000	182.05
0.5	10.27	3.004	151.75	2.968	149.89	4.000	208.79
0.6	12.05	3.254	190.89	3.163	186.88	4.000	243.22
0.7	14.40	3.557	246.47	3.347	235.19	4.000	286.28
0.8	17.53	3.925	327.05	3.522	299.57	4.000	347.97
0.9	21.73	4.370	446.27	3.691	386.85	4.000	427.89
1	27.46	4.912	626.33	3.855	507.01	4.000	536.10
	656.09		2343.60		2096.73		2622.24

EXAMPLE 2 (continued)

water depth = 40 water elevation = 49.574

y/d	pressure	theoretical profile width	theoretical horiz shear	actual profile width	actual horiz shear	constant profile width	constant horiz shear
0	2.25	1.698		1.280		4.000	
0.1	6.87	2.967	59.97	1.922	39.85	4.000	90.38
0.2	7.79	3.160	111.48	2.222	75.58	4.000	145.26
0.3	8.74	3.348	133.53	2.465	96.30	4.000	163.86
0.4	9.90	3.563	159.99	2.680	119.19	4.000	184.82
0.5	11.37	3.819	195.10	2.876	146.84	4.000	210.91
0.6	13.28	4.127	243.54	3.059	181.78	4.000	244.44
0.7	15.79	4.500	312.00	3.231	227.18	4.000	288.23
0.8	19.12	4.951	410.71	3.396	287.40	4.000	346.06
0.9	23.58	5.498	555.92	3.554	358.56	4.000	423.26
1	29.63	6.163	779.91	3.707	479.98	4.000	527.44
	656.78		2956.15		2022.76		2624.67

water depth = 35 water elevation = 44.536

y/d	pressure	theoretical profile width	theoretical horiz shear	actual profile width	actual horiz shear	constant profile width	constant horiz shear
0	2.74	2.340		1.280		4.000	
0.1	7.73	3.931	81.94	1.885	40.26	4.000	93.24
0.2	8.71	4.173	148.61	2.167	74.48	4.000	146.43
0.3	9.73	4.411	176.55	2.395	93.94	4.000	164.28
0.4	10.97	4.683	210.02	2.595	115.32	4.000	184.40
0.5	12.54	5.007	254.27	2.778	141.01	4.000	209.43
0.6	14.58	5.398	315.11	2.949	173.32	4.000	241.55
0.7	17.26	5.871	400.70	3.109	215.12	4.000	283.43
0.8	20.78	6.444	523.58	3.263	270.34	4.000	338.61
0.9	25.50	7.139	703.44	3.410	344.54	4.000	412.10
1	31.88	7.983	972.04	3.552	445.76	4.000	511.01
	646.79		3786.25		1914.08		2584.49

EXAMPLE 2 [continued]

water depth = 30 water elevation = 39.585

y/d	pressure	theoretical profile width	theoretical horiz shear	actual profile width	actual horiz shear	constant profile width	constant horiz shear
0	3.40	3.296		1.280		4.000	
0.1	8.55	5.320	115.39	1.848	40.99	4.000	96.99
0.2	9.92	5.632	203.80	2.110	73.82	4.000	148.62
0.3	11.04	5.941	240.46	2.323	92.21	4.000	165.96
0.4	12.41	6.298	284.55	2.509	112.38	4.000	185.65
0.5	14.15	6.725	343.01	2.678	136.62	4.000	210.23
0.6	16.41	7.242	423.49	2.836	167.10	4.000	241.88
0.7	19.37	7.869	536.85	2.985	206.54	4.000	283.22
0.8	23.30	8.631	699.73	3.127	258.65	4.000	337.80
0.9	28.57	9.556	938.37	3.263	328.68	4.000	410.61
1	35.70	10.682	1295.00	3.394	424.24	4.000	508.71
	648.01		5080.66		1841.23		2589.67

water depth = 25 water elevation = 34.757

y/d	pressure	theoretical profile width	theoretical horiz shear	actual profile width	actual horiz shear	constant profile width	constant horiz shear
0	4.38	4.766		1.280		4.000	
0.1	10.43	7.372	169.71	1.809	42.49	4.000	102.79
0.2	11.63	7.784	290.92	2.053	74.28	4.000	153.32
0.3	12.91	8.202	341.34	2.249	91.94	4.000	170.57
0.4	14.49	8.689	402.85	2.420	111.41	4.000	190.46
0.5	16.52	9.278	485.25	2.577	134.94	4.000	215.57
0.6	19.18	9.997	599.67	2.722	164.71	4.000	248.17
0.7	22.70	10.875	762.21	2.858	203.48	4.000	291.09
0.8	27.40	11.948	997.82	2.988	255.04	4.000	348.19
0.9	33.74	13.258	1346.40	3.113	324.84	4.000	424.97
1	42.41	14.864	1872.98	3.233	420.83	4.000	529.29
	668.93		7269.15		1823.96		2674.41

EXAMPLE 2 [continued]

water depth	summary of theoretical total shear	summary of actual total shear	summary of constant total shear
50	1912.59	2191.52	2644.17
45	2343.60	2096.73	2622.24
40	2956.15	2022.76	2624.67
35	3786.25	1914.08	2584.49
30	5080.66	1841.23	2589.67
25	7269.15	1823.96	2674.41

The summary of the actual mud line shear forces gives 2000 kN approximately for the range of water depths.

If the profile width is kept constant then the mud line shear force is 2600 kN approximately for the range of water depths.

If the real structure is not a monopile but consists of braces, other members and appurtenances, provided the summation of the projected profile widths at each elevation are comparable with the monopile actual profile widths, then the real structure will exhibit the same properties as the monopile. As various parts of the real structure will be located at different positions in the wave and at different orientations, there will be some deviation from the constant wave load expected. The wave climate will also vary for different sites, even with the same water depth. Provided the upper bound wave climate is selected, the design of the real structure will be satisfactory.

Example 3 is illustrated by Figure 5. The following data was observed and resulted in the relatively constant base shear and base moment results, at different depths, illustrated in Figures 6 and 7.

<u>Design Data</u>

Hw = 16.0m Tassoc = 12.5 sec

Surf current = 2.5 m/sec

Stoke's 5th wave   Cd = 0.7   Cm = 2.0

Mar. growth = 0.050 m (thickness)

CLAIMS

1. An offshore structure for supporting a fixture above a wave crest and over the sea bed, the sea bed being at any depth within a selected range of depths, comprising: a vertically extending central service caisson having an upper end for supporting the fixture and a lower end for positioning adjacent the sea bed; a plurality of bracing elements connected to the caisson no higher than a mid-height of the caisson; the caisson and bracing elements having a combined effective frontal profile which increases either continuously or discontinuously from the upper end of the caisson to the lower end of the caisson, with shape, dimensions and configuration for the caisson with the bracing elements being selected to produce environmental forces from wave action on the effective frontal profile which is approximately constant for any water depth within the selected range of water depths; and a plurality of foundations for attachment to the sea bed, connected to the caisson through the bracing elements.

2. An offshore structure according to claim 1, in which services are provided between the fixture and the sea bed, the services extending through the central service caisson so that the effective frontal profile of the central service caisson accommodates the services to protect the services from environmental forces and to reduce a frontal profile of the services to equal the effective frontal profile of the caisson.

3. An offshore structure according to claim 1 or claim 2, including at least one bracing element connected directly between the caisson, near mid-height of the caisson, and at least one of the foundations.

4. An offshore structure according to claim 3, including at least one additional bracing element connected between at least one of the foundations and the lower end of the caisson.

5. An offshore structure according to any one of the preceding claims, wherein each of the foundations comprises a pile, a spread footing or a suction pad for securing the caisson to the sea bed.

6. An offshore structure according to any one of the preceding claims, wherein the fixture comprises a module, a building, a deck or a platform, the caisson being sufficiently long to maintain the fixture above the wave crest.

7. An offshore structure according to any one of the preceding claims, including three or more foundations, at least two of the foundations being connected by angled bracing elements to the mid-height of the caisson on one side of the fixture, and at least one of the foundations being connected by bracing elements to a lower end of the caisson and on an opposite side of the fixture.

8. An offshore structure according to claim 7, including cross bracing elements between the angled bracing elements that are between the mid-height of the caisson and the at least two foundations.

9. An offshore structure according to claim 1 or claim 2, wherein at least one of the bracing elements is connected between two of the foundations.

10. An offshore structure according to claim 1 or claim 2, wherein each of the foundations is connected to the caisson by bracing elements that are only connected to the lower end of the caisson.

11. An offshore structure substantially as hereinbefore described and illustrated in the accompanying drawings.

12. A method of utilizing a single offshore structure for reuse at multiple water depths within a selected range of water depths, the offshore structure carrying a fixture above a water crest level, and attaching the fixture to the sea bed, comprising the steps of: designing the offshore structure to have a vertically extending central service caisson having an upper end for supporting the fixture and a lower end for positioning adjacent the sea bed; the structure having a plurality of bracing elements connected to the caisson no higher than a mid-height of the caisson, the caisson and bracing elements having a combined effective frontal profile which increases either continuously

or discontinuously, from the upper end of the caisson to the lower end of the caisson, with shape, dimensions and configuration for the caisson with the bracing elements being selected to produce environmental forces from wave action on the effective frontal profile which is approximately constant for any water depth within the selected range of water depth, and a plurality of foundations for attachment to the sea bed, connected to the caisson through the bracing elements; attaching the offshore structure at a first location having a first water depth using foundations suited to the sea bed at the first location; removing the offshore structure from the first location in preparation for attaching the offshore structure to a second location at a second water depth; adjusting the length of the caisson so that the fixture will be above the water crest level at the second location; if needed, replacing the foundations so that they are suited for anchoring to the sea bed at the second location; and attaching the offshore structure at the second location using the foundations suited to the sea bed at the second location.

13. A method of utilizing a single offshore structure for reuse at multiple water depths, the method being substantially as hereinbefore described.

24

Patents Act 1977 Examiner's report to the Comptroller under Section 17 (The Search report) (CORRECTED SEARCH REPORT)	Application number GB 9416813.5
Relevant Technical Fields (i) UK Cl (Ed.M) E1H(A) (HB, HCA, HCD) (ii) Int Cl (Ed.5) E02B 17/00, 17/02, E02D 29/06	Search Examiner KARL WHITFIELD Date of completion of Search 12 OCTOBER 1994
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii)	Documents considered relevant following a search in respect of Claims :- 1-13

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
X	GB 2267525 A	(KVAERNER) whole document relevant	1-3,5 and 6
X	GB 2136860 A	(HEEREMA) whole document relevant	1-3,5,6 and 9
X	GB 2136482 A	(HEEREMA) whole document relevant	1-3,5,6 and 9
X	GB 1037558	(WIMPEY) see especially figures and page 1 lines 50-51	1-3,5,6, 12 and 13
X	EP 0122719 A1	(HEEREMA) whole document relvant	1-3,5,6 and 9
X	WO 90/08232 A1	(MAERSK) whole document relevant	1-3,5,6 and 9

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).